Module 6. Design of Menthol Cigarettes

I. Introduction of Topics for Discussion

The design of mentholated cigarettes is extremely similar to the design of non-mentholated cigarettes. In both cases, the researcher is interested in fundamental properties of smoke generation and the transfer of that smoke to the consumer. The unique characteristics of smoke and its formation and generation which are important in designing cigarettes include: pyrolysis of tobacco, construction parameters (i.e. paper, tow, etc.), combustion, temperature gradients, and flow characteristics of the total cigarette system.

Dr. D. E. Townsend and Mr. A. B. Norman developed a course entitled "The Design of Cigarettes" which covered the above topics so that a cigarettes designer could properly understand and develop cigarettes. Their course used state of the art techniques such as modeling to aid in the design of non-menthol cigarettes. The information provided in this module builds on their course.

A. Review of Factors Affecting Menthol Migration and Smoke Menthol Transfer (1963-1983)

Since the initial introduction of full-flavor mentholated cigarettes, manufacturers have been interested in factors which affect the migration and transfer of menthol. Understanding of these factors will aid Manufacturing in determining proper methods for applying menthol (amount and placement of menthol). In addition, Marketing personnel have been interested in how the migration and transfer of menthol influences consumer acceptance. A considerable amount of work has already been done in this area.

Maintaining product stability over time is critical to product quality. The purpose of this section is to review factors, identified in previous studies, that are known to affect menthol migration and to determine which factors affect smoke menthol delivery of aged products.

1. Menthol Migration from Mentholated Filters or Mentholated Tobacco

Several studies on menthol migration have been completed, both in-house (1,2,7,10 - 12) and as shown in the literature (3 - 6). In each study, the migration of menthol from the tobacco rod to the cellulose acetate filter and vice versa was examined as either a function of the storage time or the temperature (11) of mentholated cigarettes. Several studies (2,4,7) provide sufficent information to determine the rate of mass transfer of menthol from the rod and from the filter. To date, Brozinski et al. (4) and Norman and Perfetti (12) have performed the most complete studies on the factors affecting menthol migration as a function of age. Two other studies (by Black and Swicegood (2) and McKenzie (7)) were also conducted in this area.

The cigarettes used in these studies (2,4,7) were 85mm in length, contained a plasticized cellulose acetate filter, and were approximately 1.0g in weight. The first cigarette type used a mentholated rod with no menthol applied to the filter. The second cigarette type used in the study had menthol applied to the filter yet no menthol applied to the rod. For convenience, cigarettes that have 100% of the menthol applied to the tobacco rod will be coded TOBMEN; cigarettes with 100% of the menthol applied to the filter will be coded MENFIL. In each study the two cigarettes (TOBMEN and MENFIL) were identical in all other respects (tow item, blend, paper, etc.). The cigarettes were stored at room temperature and the cigarette packs were placed in cartons. Table I shows the cigarette configurations, initial menthol contents of filters and rods, and the rates of mass transfer for the

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three studies. The data indicate that a true distribution coefficient exists for menthol migration from the filter to the rod and vice versa, which is not dependent upon the absolute amount of menthol present. The driving force for the mass transfer of menthol from the rod and from the filter is quite different in each case. The data indicate that the half-life of the reactions, or, in this case, the time at which equilibrium is reached, appears to be in the range of approximately 9 to 11 months. At this time, approximately 45 to 50% of the menthol is in the filter, irrespective of whether the menthol was originally in the tobacco or the filter. This data was confirmed in the study by Perfetti (13).

A very important consideration in the mass transfer of menthol toward this equilibrium state is the determination of the driving force. From the data in Table I, it was determined that menthol concentration was not a driving force. Regardless of the initial menthol present in any particular cigarette, the migration proceeded at the same determinable rate according to classical zero order kinetics. The three studies used cigarettes that had different blends of tobaccos. The particular blend of tobaccos may not be as important as one might expect in driving the equilibrium because nearly identical rates of transfer were calculated. As long as a "typical" blend of tobaccos is used, the same rate of transfer of menthol can be expected. This is not to say that in extreme cases the rate of migration for a cigarette prepared of 100% flue-cured would be the same as a cigarette containing 100% burley tobacco. A study should be undertaken to conclusively determine the effect that different tobacco types and blends have on the migration rate of menthol.

Additional information from other studies in the literature (1,3,4,8) have identified additional factors that influence the rate of migration:

- Temperature (Elevated)
- Solubility
- Plasticizer (Level and Type)
- Humectants
- Fiber Parameters (Total Denier, Denier per Filament)

The rate of transfer of menthol from the tobacco to the filter is temperature-dependent (4). A decrease in temperature affects the vapor pressure of menthol and significantly decreases the rate of migration (11). Additional information collected by Newell (8) from a product aging study on SALEM and SALEM ULTRA cigarettes under hot/dry and Houston Cycle (hot/wet) conditions indicates that under these conditions the overall mass transfer of menthol nearly doubles.

The solubility of menthol in cellulose acetate is appreciably greater than in tobacco. The distribution coefficient of menthol in the filter versus the tobacco used in Brozinski's study (4) was approximately 4.5:1 at equilibrium. A recent study by D. Mathis of Eastman supports this evidence (14).

The effect of triacetin and triethylene glycol diacetate on the affinity of a cellulose acetate filter for menthol is quite extraordinary (Figure 1). The percentage of menthol that migrates to filters increases with time. Interestingly, the type and concentration of the plasticizer used on cellulose acetate filters affect the migration rate (3).

The type of humectant placed on filters also can affect the rate of migration. Glycerol (3) appears to have little effect, while 1,2-propanediol (propylene glycol or B-9) significantly increases menthol migration irrespective of concentration (2) (Figure 2).

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Fiber parameters (total denier and denier per filament) have a slight effect on menthol migration. At a given denier per filament, menthol migration increases with increasing total denier. At a given total denier, menthol migration also increases with increasing denier per filament. These effects are real but less significant than the effects of plasticizer type or level (16).

The importance of moisture as a variable influencing the rate of migration of menthol is unknown. No study to date has been done to answer this particular question. Some data, however, are available on the loss of moisture with age of mentholated products (1) (SALEM 85 and SALEM 100). Cigarettes exposed to hot/dry accelerated aging showed a rapid drop in moisture content. After 20 weeks, the moisture content dropped to 7.5%. No change in percent menthol in the cigarette was noted in this 20-week test period. Also, cigarettes were placed in the Houston Cycle for 20 weeks. A moderate increase in moisture was noted but the percent menthol in the cigarettes remained constant. The rates of transfer of menthol for SALEM in either the hot/dry or the Houston Cycle (hot/wet) were almost equivalent (8). Thus, moisture variation does not appear to affect the mass transfer of menthol from the tobacco to the filter. Green et al. support these data (15). A complete study has not been done on the rate of migration of menthol from the filter to the rod with dry filter and/or dry tobacco rods.

In summary, the overall mass transfer for menthol migration from the tobacco rod to the filter takes approximately 9-11 months. The rate of migration of menthol from the filter to the rod is much quicker, approximately twice the rate of transfer of menthol from the rod to the filter, although the time to equilibration is still approximately 9-11 months. Temperature can influence the rate of mass transfer. Increases in temperature increase the rate of migration and temperature decreases slow the rate of migration. The type and concentration of plasticizers also drive the rate of migration of menthol from the tobacco to the filter. The use of 1,2- propanediol has been shown to increase the rate of migration of menthol from the tobacco to the filter. Glycerol does not appear to influence the rate of migration of menthol. The effect of moisture is not clear at this time, although it does not appear to be important in driving the mass transfer of menthol.

2. Parameters Affecting Smoke Menthol Delivery

Brozinski (4) collected data on the influence of aging on smoke menthol delivery for MENTOB and FILMEN type cigarettes. This data will be reviewed first since Brozinski's conclusions have been the basis for additional studies performed by Curran (3,5) and Perfetti (10 - 13).

The objective of Brozinski's work was to determine how menthol migrates from the filter to the tobacco rod and from the tobacco rod to the filter. A further objective was to determine whether the age of the cigarette or the initial placement of menthol (tobacco or filter) influences the delivery of menthol with aging.

Menthol distribution has been shown to be very dependent upon the method of applying menthol (MENTOB vs FILMEN) and upon the length of time that the cigarettes have been stored. It is reasonable to assume that this also has a considerable influence on the smoke menthol delivery, with respect to the distribution of the menthol in the mainstream and sidestream smoke, as well as in the filter and tobacco butt. Tables II and III present Brozinski's results on MENTOB and FILMEN and on the influence of the distribution of menthol and age on smoke menthol delivery.

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The results of Brozinski's study laid the foundation for the theory of menthol transfer to the mainstream smoke. Brozinski explained that there were three different phases that a conventionally prepared menthol cigarettes goes through in its expected shelf-life (Figure 7).

During Phase I, the freshly prepared cigarette has essentially no menthol on its filter and, thus, initially delivers smaller amounts of methol to the mainstream smoke because of its high filter efficiency. Further along in time, in Phase I, menthol very rapidly migrates to the filter and effectively decreases the cigarettes filtering effficiency for menthol. Greater deliveries in smoke menthol result.

Finally, there comes a time when the efficiency of the filter for menthol remains relatively constant - Phase II. Migration of menthol from the rod continues with time. During Phase II, the amount of menthol found in the smoke remains essentially constant in spite of the small losses of menthol during storage and despite the decrease in the percentage of menthol entering the filter. This is because these effects are over-compensated for by the great decrease in filter efficiency resulting from the increasing pre-loading of the filter with menthol.

As the length of storage time incereases, there is eventually a decrease in the amount of menthol in the smoke - Phase III. During this period, menthol is believed to be more deeply sorbed into the filter and thus is not available for elution. Menthol is also sorbed into the tobacco and may be either chemically altered or pyrolyzed on smoking and therefore, is not analyzed as smoke menthol. In either or both cases, a decrease in smoke menthol has been observed upon long storage.

Bustle injection is thought to result in the partial or total elimination of Phase I by essentially displacing the shelf-life curve to the left (See Figure 7); or, in other words, the filter is pre-loaded with menthol to the point of relatively constant smoke menthol delivery. As previously discussed, this hypothesis can b used to explain the differences in curve shapes (10,13).

Construction parameters and menthol load only affect the magnitude of the smoke menthol delivery, not the shape of the curve or the position along it. The shape and position of the curve appear to be dependent on those factors that affect the rate of migration of menthol in the cigarette models.

Brozinski also did a comparative study on eight commercially available mentholated cigarettes from the United States and Germany. Some of the cigarettes were 85mm in length and others were 100mm in length. The filter lengths varied (18-25 mm) as well as the filter weights (120-125 mg), resistance to draw (53-75 mm H_2O), and nicotine filtering efficiencies. The cigarettes contained between 0.125 and 3.19 mg of menthol in the whole cigarette. The percentage of menthol in the filter varied between 25 and 42%. The exact age of the cigarette was unknown, but most were at least several months old. The eight cigarettes certainly comprised a varied collection of mentholated products.

Table IV shows the results of Brozinski's analyses of these cigarettes. The amounts of menthol found in the smoke are parallel to the amounts of menthol found in the whole cigarette before smoking. However, when the percent smoke transfer is calculated, the range is narrow (24-31%). For all brands investigated, the "apparent" retention was between 60 and 72% and, thereby, in the same range as the experimental cigarettes MENTOB and FILMEN (No. 1-6, Table II). The filter balance was between 0.07 and -0.04; i.e., the "true" retention and elution of menthol in all cases were nearly equal. Therefore, the mechanism of menthol delivery does not appear to be related to the

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initial concentrations of menthol, the configuration, blend (assuming the 8 cigarettes had varied blends), pressure drop, filter weight, or mass of filter. The important factor is age, that is, how far the mass transfer has proceeded, since this will affect the amount of pre-loading on the filter which in turn affects the filter efficiency for menthol and ultimately the amount of smoke menthol delivered.

The work of Curran (5) concentrated on the per puff deliveries of menthol with aging for cigarettes that had 100% of the menthol initially placed on the filter (Cigarette F) and 100% of the menthol initially placed on the tobacco (Cigarette T) (see Table V). The investigation time was 28 days. Figures 3 and 4 show the effects of age and menthol placement on menthol delivery per puff. It is interesting to note that initial placement of menthol in the cigarette drastically affects the per puff deliveries. After 28 days, though, the per puff profiles for menthol delivery are converging. As menthol, initially placed in the filter, migrates to the tobacco rod, the pre-loading phenomenon diminishes and filter efficiency for menthol increases as can be seen in Table V. Eventually, as migration continues, menthol transfer for Cigarette F will approach Cigarette T, as predicted by Brozinski's work, until the "true" menthol retention equals zero, or, in other words, until menthol transfer remains essentially constant. At this point in time, approximately 2-3 months, (dependent upon other factors which might affect the migration rate of menthol in the cigarette) approximately 20-35% of the menthol will be in the filter and 65-70% of the menthol will be present in the tobacco (Figure 5).

A study by Riehl et al. (6) investigated possible explanations for the increased deliveries of menthol in Cigarette F compared to Cigarette T during the final puffs for cigarettes aged for 28 days (Figure 4). He rationalizes that increases in filter temperature, aerosol concentration, and aerosol unit surface area offer ready explanations for the increases. However, his arguments were very weak and were not pursued.

Other factors may be responsible for variations in smoke menthol delivery. A second study by Curran (3) examined the influence of filter plasticizers and humectants on menthol delivery. Tables VI and VII present data on the effects of different plasticizers and humectants at various concentrations on menthol delivery. Cigarettes were aged 6 weeks and smoked at 1-, 3-, and 6-week intervals. During the 6 weeks of aging, menthol migrated from the rod to the filter. Plasticizers increased the migration rate substantially when compared to control samples. The humectant 1,2-propanediol also increased the rate of migration of menthol to the filter, while glycerol appeared to have no effect. The smoke menthol results indicate no correlations between the menthol delivery and the filter's affinity for menthol. Triacetin appears to decrease the filter's efficiency for menthol, and, as a result, more menthol is delivered. The plasticizer triethylene glycol diacetate as well as the humectants, glycerol and 1,2-propanediol, appear to increase filtering efficiency of these cigarettes for menthol. As a result, cigarettes containing these additives have decreased menthol deliveries. Additional data from the study by Black and Swicegood (2) indicate that propylene glycol acts in a similar manner to glycerol.

The level of moisture alone does not appear to affect menthol delivery. Cigarettes aged in the hot/dry cycle and Houston cycle (hot/wet) for 20 weeks showed drastic changes in moisture (1). Cigarettes aged in the hot/dry cycle were reduced in moisture to 7.5% after 20 weeks. The same cigarettes in the Houston cycle showed no significant change in moisture (12.3%) After exposure to either treatment, smoke menthol decreased 10% after two weeks and approximately 25% after 20 weeks. Therefore, the small changes in moisture did not account for the decrease in menthol delivery. Other factors must be important in affecting the decrease in menthol delivery. Wallace (17) performed experiments in 1982 on Salem KS known as the Controlled Environment

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Aging Study. Wallace varied temperature and relative humidity in a controlled manner on packages of Salem KS and monitored the delivery of smoke menthol with time. The results are seen in Figure 6. The effect of relative humidity on smoke menthol delivery is quite dramatic and appears to be greater than temperature alone. The moisture of the products shown in Figure 6 remained relatively constant (since the products were sealed in packages in dessicators). As the temperature increased and the relative humidity increased smoke menthol decreased. Wallace believed that this was the result of increased migration of menthol to the cellulose acetate fiber and increased sorption of menthol into the fiber thus leaving less menthol available for delivery/elution into the mainstream.

Packaging is also important since it can affect the amount of menthol available for delivery. Dube (18,19) examined the loss of menthol to packaging materials as a function of time and temperature by monitoring the loss of menthol from the cigarettes and the decrease in smoke menthol deliveries (Table VIII).

There were no significant differences in the levels of pack menthol, smoke menthol, or pack moisture between the Crush-Proof Box (CPB) and Soft Pack (SP) products over the test period for any of the temperatures. There was a two-and-a-half fold increase in the amount of menthol sorbed by the CPB packaging material stored at 100°F when compared to the SP material at the same temperature; however, because this increase amounted to only 5% of the total pack menthol, it was not seen as significant for the 20-pack products. This small menthol loss became notable in the sample 4-pack CPB and appears to be significant enough to warrant adjustment of initial menthol load in these products. The 20-pack CPB and SP packaging materials appeared to be saturated within 30 days.

Finally, environmental factors can affect smoke menthol delivery. Wagoner (20) and Perfetti et al. (21) examined the rate of loss of menthol for cigarettes that were both packed and loose. Mentholated products open to the atmosphere (stored loose) lost 10% of the available menthol within 24 hours and over 50% of the menthol within 6 days compared to packaged products. Smoke menthol also decreases dramatically. Perfetti reported (21) a 38% decrease in smoke menthol delivery over 8 hours for loose product (Tables IX and X).

Because a substantial amount of work on charcoal filters has been completed in-house and because there are filters commercially available, the topic of mentholated charcoal filters will be discussed. Newell, Latimer, and Moser (22,23) explored the influence of aging of mentholated products having bonded-charcoal filters (23). They found that during aging the bonded-charcoal absorbed and held an increasing portion of the menthol, making it unavailable to the mainstream smoke (Table XI).

In a seperate experiment Newell et.al. (23) investigated the use of dual filters containing estron and estron impregnated with charcoal and binder. These cigarettes were compared to normal estron filters. The mainstream delivery of menthol from the dual filters was found to be negligible (Table XII). In general, the consensus of personnel in the tobacco industry is to beware of charcoal when dealing with volatile organic flavorants if you are trying to deliver those flavorants to the mainstream smoke. Newell found one very significant result (22). When heated in the presence of menthol in a closed vessel, finely divided charcoal forms a menthol-charcoal complex. When this complex was blended with tobacco and made into cigarettes, menthol was transfered into the mainstream smoke. When the test cigarette was smoked against a control having a similiar amount of menthol per cigarette, nearly equivalent deliveries were achieved. Additionally, the menthol migration from rod to filter was decreased appreciably (Table XIII).

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3. Conclusions

- The rate of mass transfer of menthol at room temperature follows zero order kinetics and is, therefore, not concentration-dependent. The amount of menthol at any time can be determined if the initial concentration and placement of menthol are known.

- Increases in temperature and relative humidity substantially increase the sorption and rate of mass transfer of menthol.

- Plasticizers and humectants in filters affect the rate of mass transfer of menthol from the filter to the rod. The rate is dependent on the type and concentration used.

- Fiber parameters affect menthol migration.

- Solubility of menthol is a driving force in the rate of mass transfer of menthol. The distribution coefficient of menthol in cellulose acetate versus tobacco is 4.5:1 at equilibrium.

- Moisture alone does not appear to affect the rate of mass transfer of menthol.

- The tobacco blend does not appear to affect the rate of migration of menthol.

- The delivery of smoke menthol is dependent on the age of the cigarette or, more precisely, on the percent of menthol present in the tobacco and filter at any given time.

- Packaging parameters and environmental conditions can affect menthol loss and delivery.

- Freshly prepared cigarettes containing nearly 100% of the menthol in the rod and very little menthol in the filter deliver less menthol than aged cigarettes because the filter efficiency of fresh filters is higher than it is for aged filters. As aging proceeds, pre-loading of menthol from the migration of menthol to the filter decreases the filter efficiency for menthol and thus increases transfer. As aging continues, the amount of menthol remaining in the rod decreases to 50-60% (near equilibrium) and the menthol present in the filter begins to sorb into the cellulose acetate. As less menthol is available for elution, menthol delivery begins to decrease again. This entire scenario is, of course, dependent upon those factors which affect migration. Therefore, temperature, plasticizers, humectants, solubility, and fiber parameters are important factors in menthol delivery of aged cigarettes.

- The use of carbon filters is not recommended for mentholated products because the sorption of menthol by charcoal is very great and delivery from products with charcoal filters is negligible.

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TABLE I. MENTHOL DISTRIBUTION AND TRANSFER RATES

Study	Code	Wt.,Rod/ Filter (g)	Menthol Conc. (mg/g)	Total Menthol Applied (mg)	Length of Study (d)	Mass Transport Data			
						Direction	Rate mg/g-d	Correction	Life (d)
Brozinski	TOBMEN	.95/.16	2.89	2.74	390	Tob > Filt	.0021	-.901	330
Brozinski	MENFIL	.95/.16	6.23	1.0	90	Filt > Tob	.0048	-.937	144
Black	TOBMEN	.90/.18	2.45	2.21	120	Tob > Filt	.0028	-.978	248
	MENFIL	.90/.18	1.44	0.26	120	Filt > Tob	.0045	-.863	154
		.90/.18	2.61	0.47	120	Filt > Tob	.0039	-.780	177
McKenzie	TOBMEN	1973 Vantage M 85, SCS Filter	----	2.85	240	Tob > Filt	.0029	-.926	238

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Table II*

Cig No.	Time (Months)	MENTHOL BEFORE SMOKING Rod mg/cig	Filter mg/cig	Cig mg/cig	% in Filter	MENTHOL AFTER SMOKING Smoke mg/cig	Filter mg/cig	Total mg	Apparent Retention, %
1	0	2.86	0.02	2.88	0.7	.39	0.67	1.06	63.2
2	1	1.85	0.49	2.34	20.9	.44	0.61	1.05	58.1
3	3	1.90	0.81	2.71	29.9	.52	0.84	1.36	61.8
4	5	1.69	0.93	2.62	35.5	.48	0.94	-1.41	66.0
5	9	1.71	1.23	2.94	41.8	.43	1.18	1.61	73.3
6	0	0.00	1.00	1.00	100.0	.29	0.63	0.92	68.5

No. 6 = FILMEN

No. 1 - 5 = MENTOB

Table III*

Cig No.	Time (Months)	% Menthol in Filter	Menthol in Rod (mg/cig)	Menthol Entering Filter (mg/cig)	(%)	Menthol Balance Filter (mg/cig)	% True Retention	Menthol Transfer to Smoke (mg/cig)	(%)
1	0	0.7	2.86	1.04	36.4	0.65	62.5	0.39	13.6
2	1	20.9	1.85	0.56	30.3	0.12	21.4	0.44	23.6
3	3	29.9	1.90	0.55	29.0	0.02	5.5	0.52	27.4
4	5	35.5	1.69	0.48	28.4	0.0	0.0	0.48	28.4
5	9	41.8	1.71	0.38	22.2	-0.05	-13.2	0.43	25.2
6	0	100.0	0.00	----	----	-0.29	----	0.29	----

*Data from Brozinski (1972), Reference 4

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TABLE IV. COMPARATIVE ANALYSES OF CIGARETTE BRANDS*

	BEFORE SMOKING				AFTER SMOKING					
Brand	Rod (mg/cig)	Filter (mg/cig)	Cigarette (mg/cig)	% Menthol in Filter	Menthol (mg/cig)	Smoke Menthol (mg/cig)	Filter Menthol (mg/cig)	Total Retention (%)	Apparent Balance (mg/cig)	Filter Smoke Transfer (%)
A	2.11	1.08	3.19	33.9	0.63	1.12	1.75	64.0	0.04	29.9
B	1.95	0.86	2.81	30.6	0.56	0.88	1.44	61.1	0.02	28.7
C**	1.58	0.77	2.35	32.8	0.49	0.76	1.25	60.8	-0.01	31.0
D	1.70	0.57	2.27	25.0	0.42	0.64	1.06	60.4	0.07	24.7
E	1.29	0.77	2.05	37.3	0.38	0.76	1.14	66.7	-0.01	29.5
F	1.13	0.83	1.95	42.3	0.31	0.81	1.12	72.4	-0.02	27.5
G	1.00	0.50	1.56	35.9	0.31	0.52	0.83	62.7	-0.04	31.0
H	0.079	0.046	0.125	36.8	0.019	0.035	0.054	64.8	-0.01	24.1

*Data from Brozinski (1972), Reference 4.

**100 mm cigarette.

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TABLE V. THE EFFECTS OF CIGARETTE AGE AND MENTHOL PLACEMENT ON MENTHOL DELIVERY*

Age (days)	Cigarette F[a]		Cigarette T[b]	
	mg/cig	%	mg/cig	%
3	0.92	49	0.48	20
28	0.59	31	0.45	19

[a]1.88 mg of menthol applied to filter

[b]2.34 mg of menthol applied to tobacco

*Data from Riehl et al., (1973), Reference 6.

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TABLE VI. EFFECT OF PLASTICIZER ON MENTHOL DELIVERY*

Plasticizer	Level	Menthol delivered, mg/cig** 1 wk	3 wk	6 wk	$\bar{x}$
Control	0%	0.35	0.34	0.32	0.34
Triacetin	5%	0.37	0.41	0.38	0.39
	8%	0.34	0.37	0.36	0.36
Triethylene Glycol Diacetate	5%	0.34	0.35	0.31	0.33
	8%	0.32	0.32	0.27	0.30

*Data from Curran (1972), Reference 5.
**Each value is an average of three runs.

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TABLE VII. EFFECT OF GLYCEROL AND 1,2-PROPANEDIOL ON MENTHOL DELIVERY*

		Menthol delivered, mg/cig**			
Additive	Level	1 wk	3 wk	6 wk	$\bar{x}$
Control	0%	0.34	0.37	0.36	0.36
Glycerol	6%	0.32	0.31	0.27	0.30
	10%	0.32	0.30	0.27	0.30
1,2-Propanediol	6%	0.31	0.29	0.27	0.29
	10%	0.31	0.27	0.22	0.27

All filters contained 8% triacetin.

*Data from Curran (1972), Reference 5.
**Each value is the average of three runs. All filters contained 8% triacetin.

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TABLE VIII: ANALYSIS OF AGING CPB AND SP CIGARETTES FOR MENTHOL AND MOISTURE*

Analysis	Test Day	Date	CPB A (40 °F)	CPB B (70 °F)	CPB C (100 °F)	SP D (40 °F)	SP E (70 °F)	SP F (100° F)
Pack Menthol (Avg. of 3, %)	2	1/19	0.67	0.66	0.66	0.64	0.67	0.63
	8	1/25	-----	----	0.61	----	----	0.61
	15	2/1	0.64	0.64	0.62	0.63	0.66	0.63
	22	2/8	-----	----	0.62	----	----	0.66
	29	2/15	0.64	0.63	0.60	0.62	0.63	0.62
	43	3/1	0.63	0.61	0.59	0.61	0.62	0.61
	50	3/8	0.62	0.63	0.61	0.63	0.64	0.63
	57	3/15	0.62	0.59	0.61	0.62	0.63	0.62
Smoke Menthol (Avg. of 3, mg/cig, ug/puff)	2	1/19	0.41/47	0.40/48	0.42/50	0.37/45	0.40/46	0.42/48
	8	1/25	-------	-------	0.37/45	-------	-------	0.37/43
	15	2/1	0.42/50	0.43/54	0.36/45	0.42/49	0.44/53	0.37/43
	22	2/8	-------	-------	0.35/43	-------	-------	0.34/40
	29	2/15	0.41/48	0.42/50	0.31/38	0.42/49	0.42/50	0.30/37
	43	3/1	0.49/56	0.47/56	0.32/40	0.45/51	0.45/53	0.29/36
	50	3/8	0.42/51	0.39/48	0.29/37	0.44/53	0.43/53	0.30/36
	57	3/15	0.50/58	0.41/51	0.31/38	0.44/51	0.43/51	0.28/35
Moisture (Avg. of 2, %)	2	1/19	11.96	12.17	12.12	12.54	12.43	12.56
	29	2/15	12.11	12.00	12.02	12.28	12.39	12.44
	50	3/8	12.10	12.21	11.60	12.49	12.54	12.02
	57	3/15	12.01	12.14	11.48	12.48	12.45	11.93

*Data from Dube (1982), Reference 19.

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TABLE IX. LOSS OF MENTHOL FOR CIGARETTES STORED LOOSE AND IN PACKAGES*

Brand	Type	Time Lapse, days	Menthol %	Menthol Loss, %
SALEM 85	Packed	2	.49	
SALEM 85	Loose	2	.45	8.2
SALEM 85	Packed	6	.44	
SALEM 85	Loose	6	.21	52.3
NOW M 100	Packed	2	1.37	
NOW M 100	Loose	2	1.27	7.3
NOW M 100	Packed	6	1.23	
NOW M 100	Loose	6	.51	58.5

*Data from Wagoner (1983), Reference 20.

TABLE X. MOISTURE AND MENTHOL LOSES FOR CIGARETTES STORED OPEN TO THE ENVIRONMENT ON ASHTRAYS*

Time (hrs)	Microwave** Moisture, %	Moisture Loss, %	Tobacco Rod Menthol, %	Smoke Menthol, mg/cig
Initial	11.48	0	1.79	0.34
1	11.53	0.045****	-----	-----
2	10.85	5.49	-----	-----
3	10.37	9.67	1.69	.28
4.5	10.06	12.37	-----	-----
5.5	10.15	11.59	-----	-----
6.5	9.60	16.38	1.60	.26
7.5	9.63	16.11	-----	-----
8.5	9.39	18.21	1.59	.21
24***	9.77	14.90	-----	-----
R.H.	50%			
Temp.	76°F			

*Data from Perfetti et al. (1981), Reference 21.
**All moisture and menthol values are averages of at least two determinations.
***R.H. and temperature increased overnight to 60% R.H. and 78°F. This may account for the increase in moisture in the last reading.
****Moisture gain.

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TABLE XI

ADSORPTION OF MENTHOL FROM TOBACCO BY THE BONDED CHARCOAL FILTER OF TEST CIGARETTE 700-B*

Age (Days)	Menthol (mg,/10 g. of tobacco) Charcoal	Tobacco	Total	Dev.	% of Menthol in Charcoal Filter**
1	3.8	55.2	59.0	.3	6.4
3	6.8	53.6	60.4	1.1	11.5
5	10.1	47.9	58.0	1.3	17.0
8	12.3	46.3	58.6	.7	20.7
11	16.3	45.4	61.7	2.4	27.5
14	18.1	40.2	58.3	1.0	30.5
18	22.1	38.8	60.9	1.6	37.3
22	24.4	35.0	59.4	.1	41.1
28	27.3	33.7	61.0	1.7	46.0
32	24.3	37.1	61.4	1.1	41.0
40	29.2	27.6	56.8	2.5	49.2
58	35.9	22.8	58.7	.6	60.5
123	45.6	11.2	56.8	2.5	76.9
		Av.	59.3 ±	1.3	(2.2%)

* Data from Newell et al. (1964), Reference 22.

** Calculated from the average (59.3 mg.)

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Table XII

PERCENT RECOVERY OF MENTHOL FROM MAINSTREAM OF SALEM CIGARETTES WITH ESTRON AND DUAL (ESTRON/CHARCOAL FILTERS*

	Estron Filters (%Menthol)	Dual Filters (%Menthol)
	21.2	1.7
	21.6	3.4
	19.7	1.7
Av.	20.8	2.3

*Data from Newell et al. (1963), Reference 23.

TABLE XIII. RELEASE OF MENTHOL FROM A CHARCOAL-MENTHOL COMPLEX*

L-739 (Test)

Age (d)	Menthol Found (mg.)** Filter	Tobacco	(Total)	Smoke
1	0.2	18.9	(19.1)	1.4
15	1.8	22.6	(24.4)	1.4
L-74- (Control)				
1	1.	17.	(18.0)	1.6
15	7.5	11.4	(18.9)	1.

* Data from Newell et al. (1964), Reference 22.
** Calculated as menthol (mg.) per 10 g. of tobacco or the equivalent.

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FIGURE 1. EFFECT OF PLASTICIZER ON MENTHOL MIGRATION.

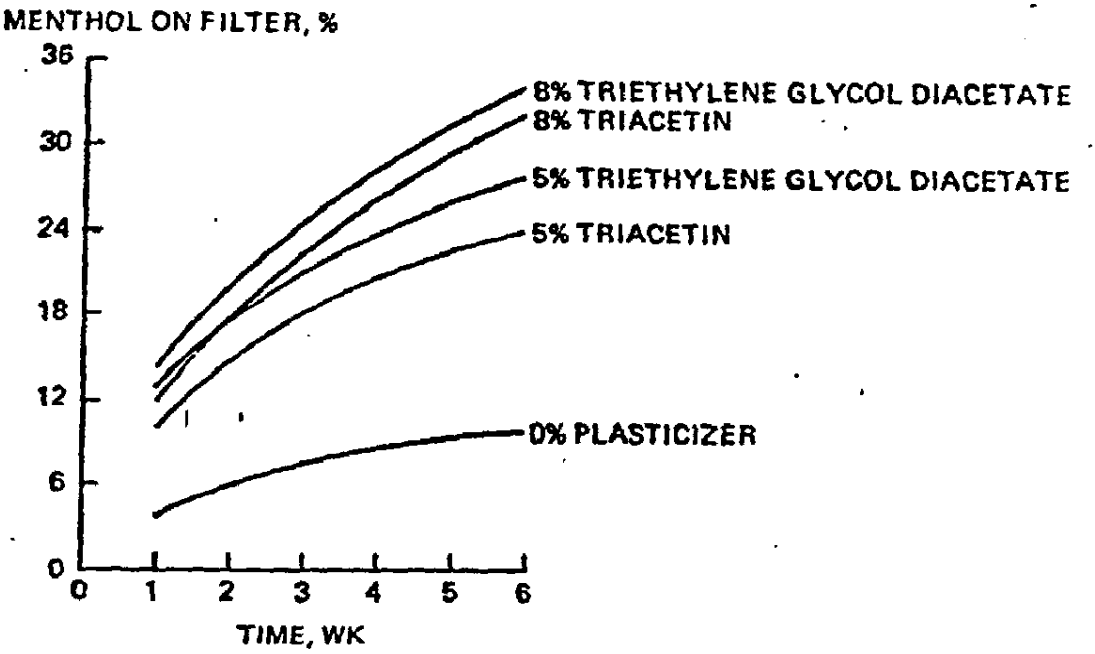

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FIGURE 2. EFFECT OF GLYCEROL AND 1,2-PROPANEDIOL ON MENTHOL MIGRATION.

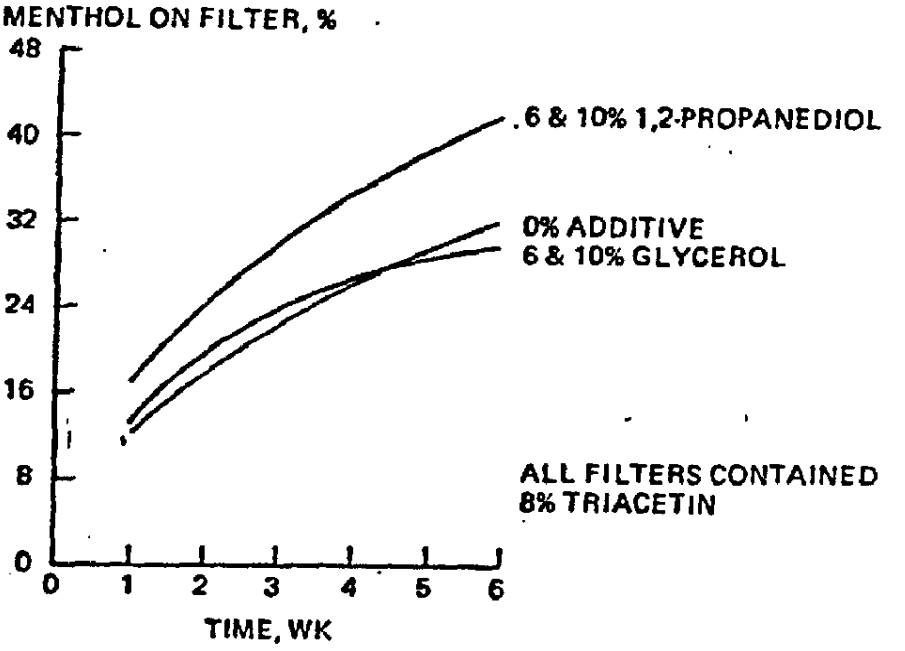

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FIGURE 3. THE MIGRATION OF MENTHOL WITHIN A MENTHOLATED CIGARETTE

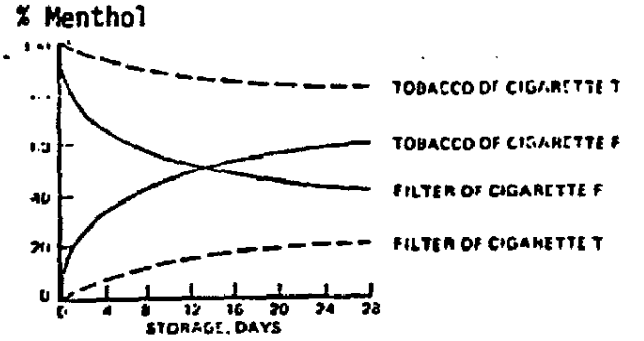

FIGURE 4. THE EFFECT OF MENTHOL PLACEMENT AND AGE ON MENTHOL DELIVERED

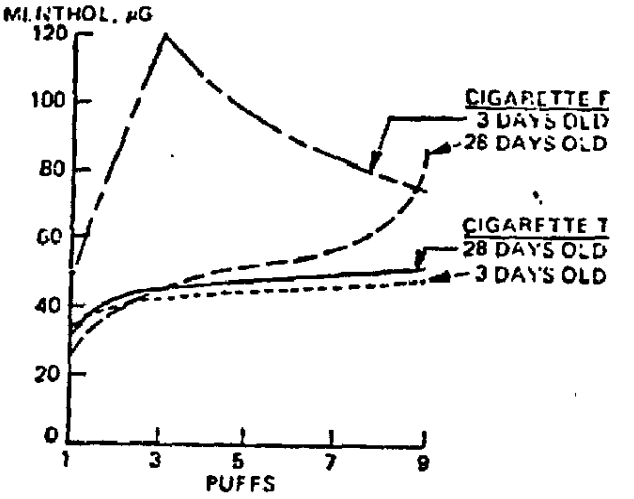

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FIGURE 5. MENTHOL TRANSFER TO SMOKE FROM DIFFERENT MENTHOL DISTRIBUTIONS

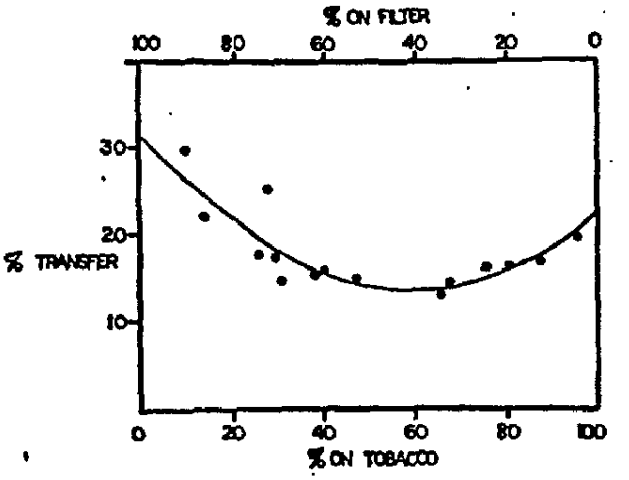

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FIGURE 6. SMOKE MENTHOL DELIVERY (SALEM 85) FROM CONTROLLED ENVIRONMENT AGING STUDY 1982 BY G. W. WALLACE

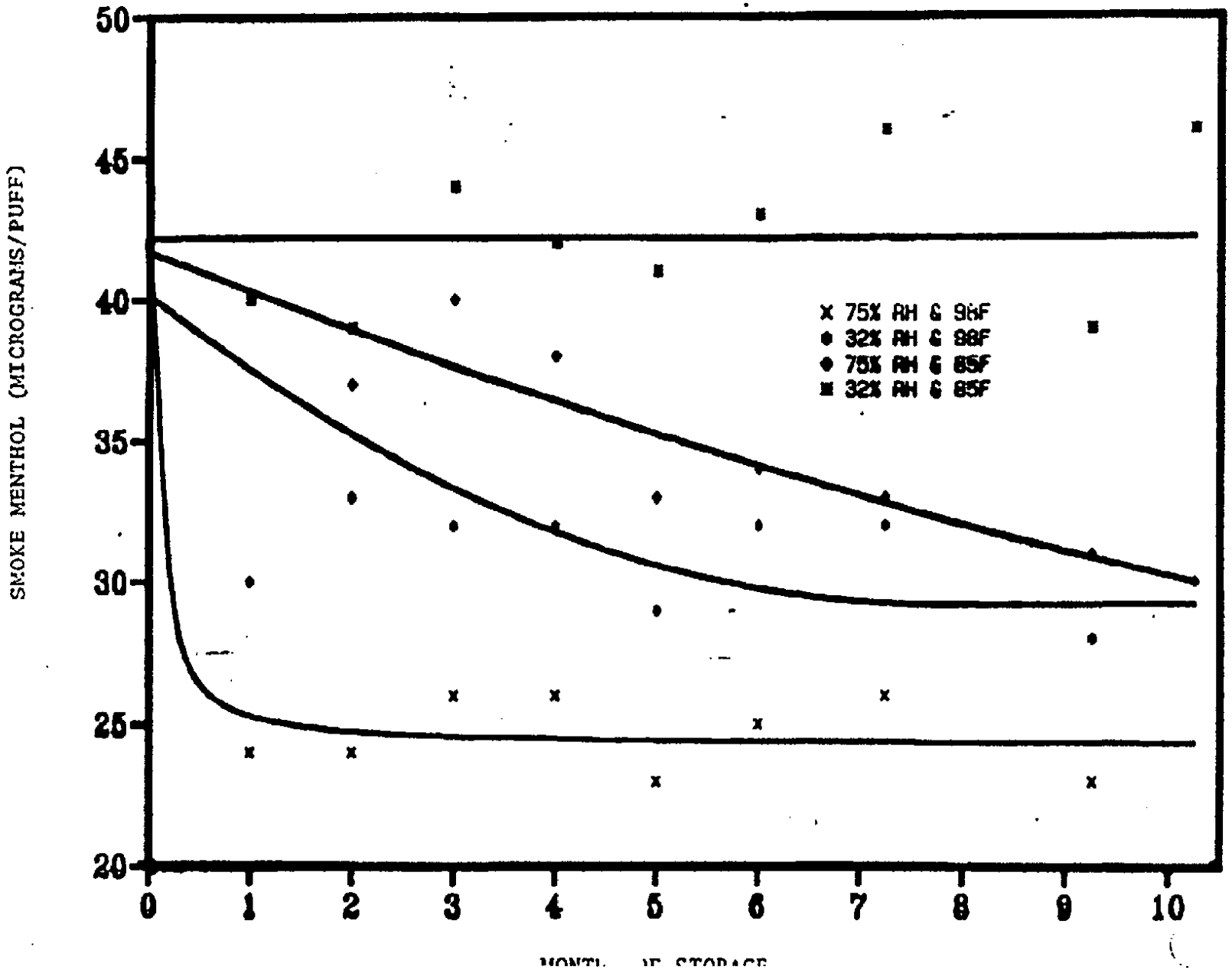

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FIGURE 7. PROPOSED THEORY OF MENTHOL MIGRATION/DELIVERY FOR BUSTLE INJECTED AND CONVENTIONALLY PREPARED CIGARETTES.

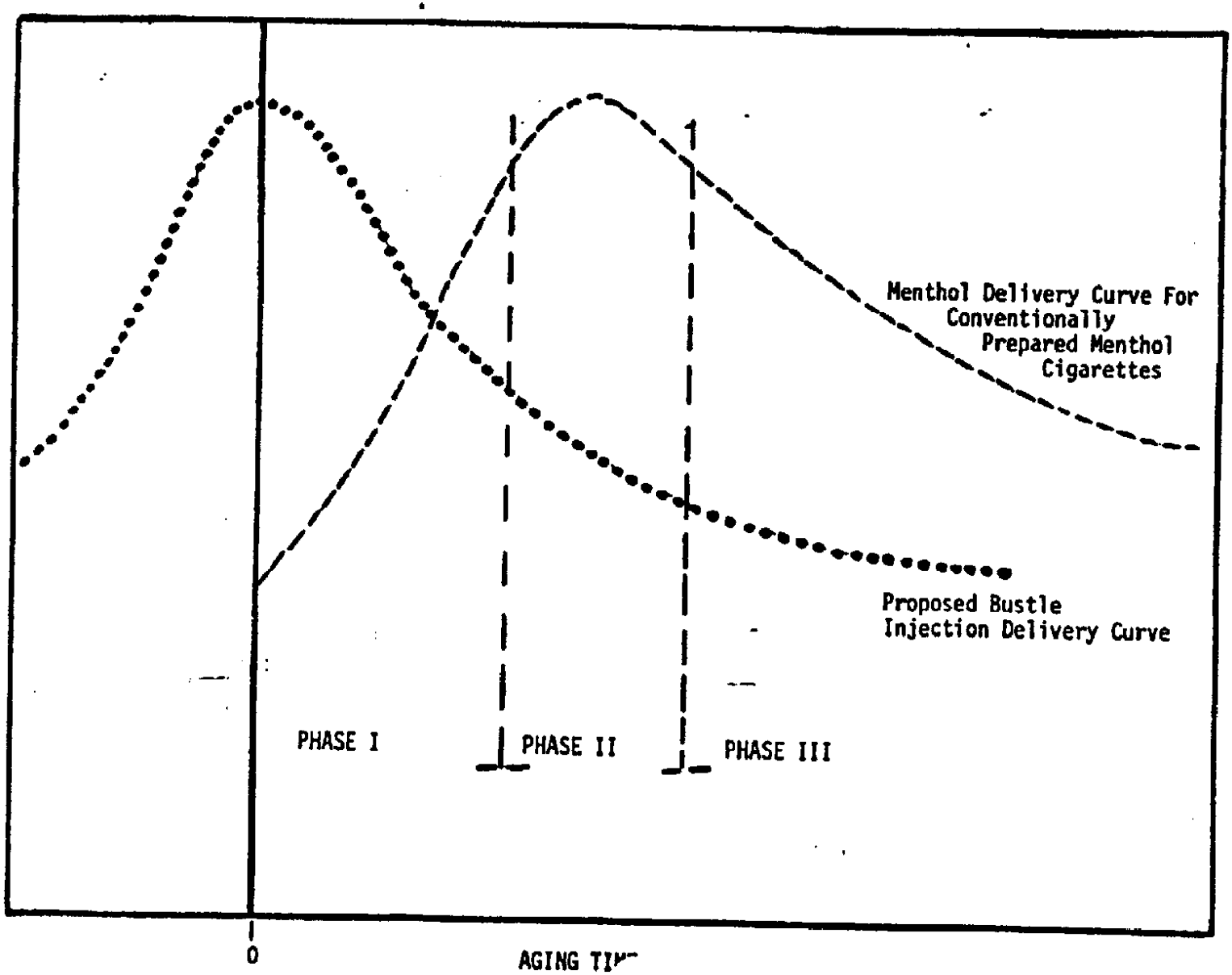

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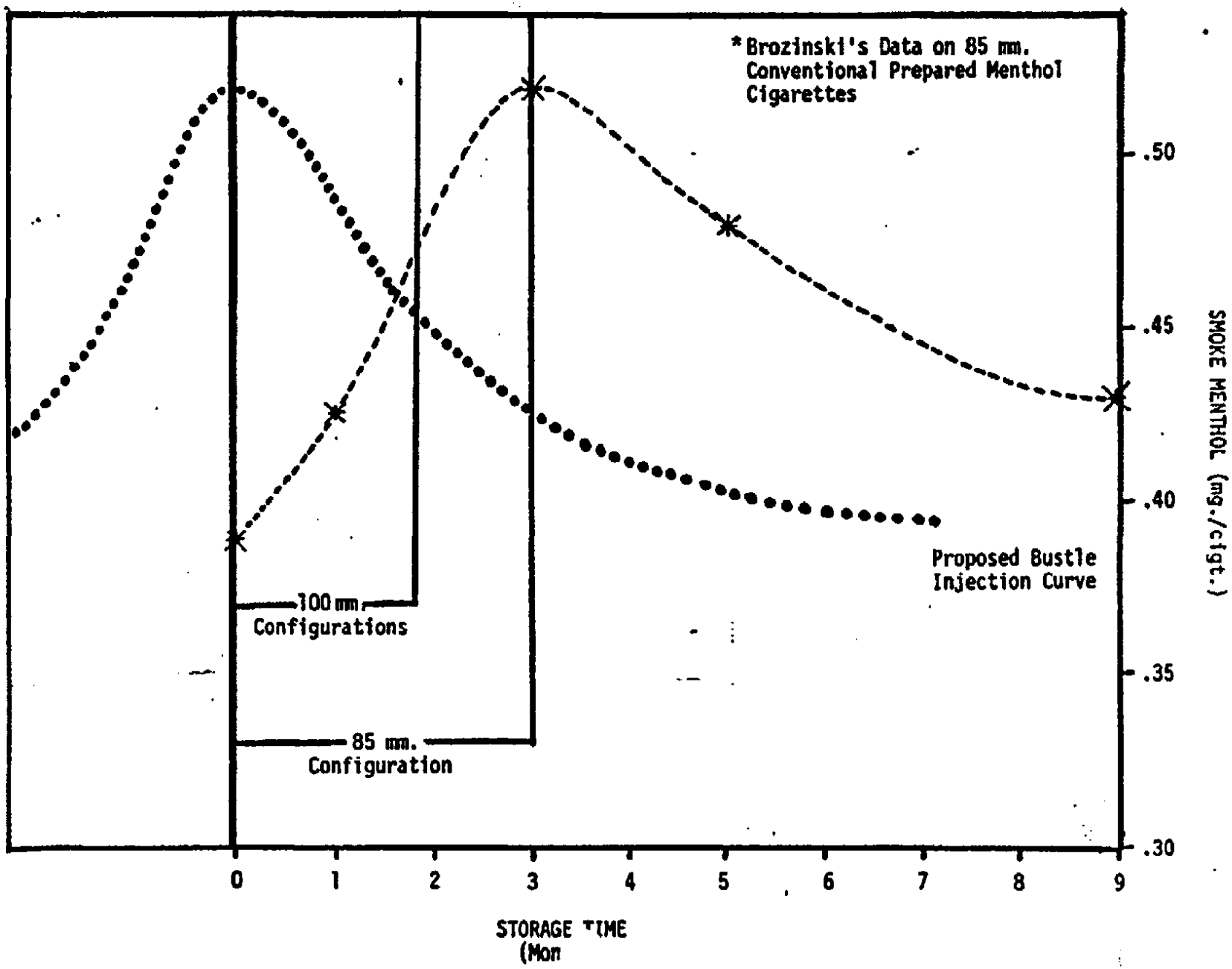
FIGURE 8. COMPARISON OF 85mm AND 100mm MENTHOL CIGARETTE DELIVERIES BASED ON PROPOSED THEORY



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